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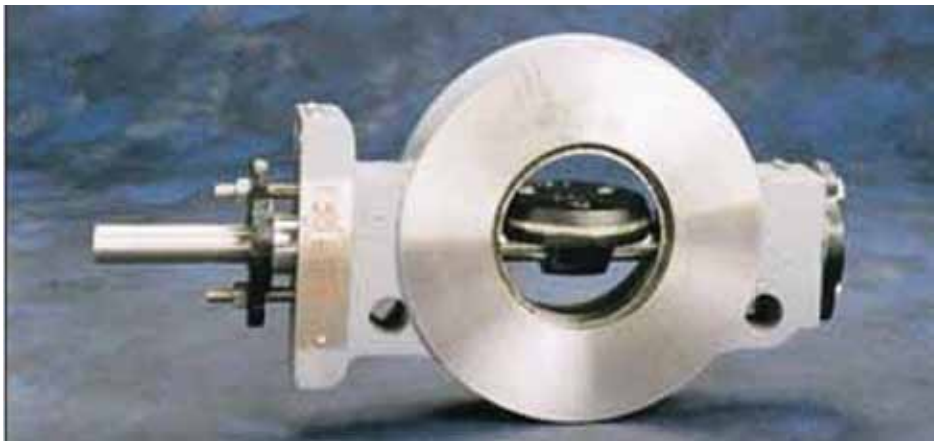
Butterfly valves for extreme temperatures

Cryogenic applications in industry become more and more important especially since LNG (liquid natural gas) gains a higher and higher proportion in power generation. In such cryogenic applications, butterfly valves are used increasingly often in order to control the liquid media in the pipeline. Until now, a typical triple offset butterfly valve with laminated seal would be used for suchlike applications. The British Standard 6364 is specifying the test methods and allowable leakage rates for cryogenic applications. Although these allowable leakages are very high and are to be measured with a flow meter in ranges of gallons per minute, it is still very hard to meet these requirements. Primarily in bigger sizes and temperatures below -50°C (-58°F) it is hard to pass the test with common triple offset butterfly valves.

By Dr Gregor Gaida, müller co-ax ag

All physical and mechanical literature is claiming that the heat expansion of isotropic metal materials is linear with increasing or decreasing temperatures. In fact, this would mean that the round bore would remain round independently of the temperature and independently of the shape of the part. This theory is right even up to very high temperatures such as 1000°C (1832°F). As this theory is proven right, all parts of a butterfly valve will expand to the same extent and in the same proportion. Although all parts are bigger at elevated temperatures their shape and proportions remain unchanged. As the thermal expansion of all used materials is almost the same, many triple offset butterfly valves have passed the fire safe test in accordance with API 607.



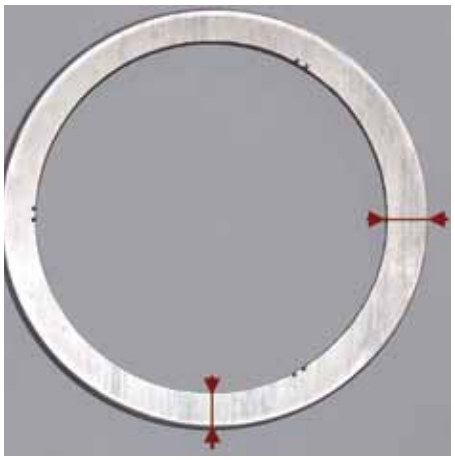
Typical triple offset valve body. Poor disc design causes shaft deflection. Big differences in wall section cause asymmetrical shrinkage.

Unfortunately, the above theory does not apply for low temperatures. In temperatures of -50°C (-58°F) and below, the shrinkage of isotropic metallic materials is different depending on the wall section. In areas where the wall section is bigger, the shrinkage is different compared to areas where the wall section is smaller.

Measurements of metallic parts cooled down to cryogenic temperatures of -196°C (-321°F) prove that in a non-symmetric part, the bore which was round at ambient temperatures will become oval. This is the main reason why it is so difficult to pass the British Standard 6364 cryogenic test with a triple offset butterfly valve especially in larger valve sizes.

A typical triple offset butterfly valve body has a much higher wall section and consists of much more material in the area where the shaft bore is placed. In addition, all triple offset butterfly valves have an elliptical seat area in the body, and due to this, the wall section of the seat area is even bigger in the shaft area than perpendicular to it.

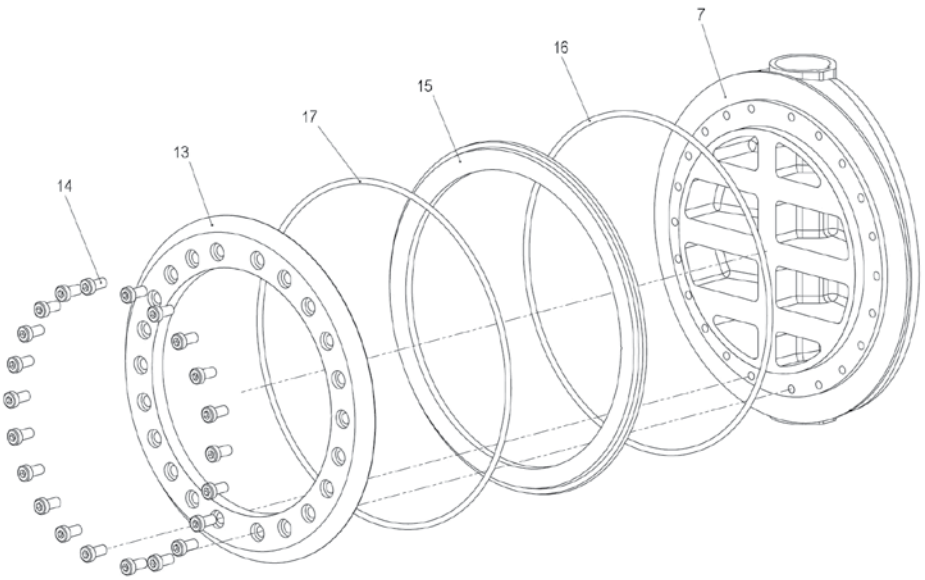
The typical lamination of a triple offset butterfly valve has a round bore in the middle and an elliptical shape on the outside. The wall section of the lamination is smallest in the shaft area and the biggest perpendicular to it. The wall section of the lamination will be the smallest right where the wall section of the body will be the biggest. Due to the non-linear shrinkage of the steel at cryogenic temperatures, the shrinkage of the body will be higher especially in the area where the shrinkage of the lamination will be



Typical triple offset laminated seal. Big differences in wall section cause asymmetrical shrinkage.

Cryogenic test of QUADAX in accordance to BS6364. Zero leakage.

smaller. The parts, perfectly fitting at ambient temperature, do not match any more at cryogenic temperatures.
The newly invented four offset butterfly valve QUADAX is able to reach zero leakage at -196°C (-321°F) during the test in accordance with British Standard 6364. The evolution of the triple offset butterfly valve to a four offset butterfly valve has eliminated several disadvantages especially for cryogenic applications. The elliptical seat area of a triple offset butterfly valve was "stretched" until it reached the round shape of the QUADAX. Furthermore, the seat bore is much bigger compared to those of all other triple offset butterfly valves existing on the market. Due to this design, the seat area has the same wall section all around the body. The body of the QUADAX itself has been optimized in order to reach an almost round shape also on the outside. With this design it is possible to keep the shrinkage of the materials homogeneous all around the valve body. Now since the wall sections are constant all around the valve body the shrinkage is constant and although all the parts shrink all the shapes remain the same and all the parts fit to each other. In this way zero leakage at -196°C (-321°F) can be achieved.
In a typical triple offset butterfly valve a normal seal would be a lamination made of sheets of graphite and stainless steel. Graphite becomes very rigid at low temperatures and the flexibility of the whole seal becomes very small. So this lamination is not able to close the gaps between the seat and the seal which grows with decreasing temperature because of the above mentioned different shrinkage of the lamination and of the valve body. A second version of a typical seal in a triple offset butterfly valve would be a lamination which is made of sheets of PTFE and stainless steel which remains flexible at very low temperatures. Unfortunately, due to the shrinkage of the PTFE which is much higher than the shrinkage of the stainless steel, screws in the clamp ring may lose their load and the seal may become untight between the disc and the seal itself.
For such difficult applications like cryogenic or liquid natural gas, QUADAX valves have an inconell O-ring serving as seal between the disc and the valve seat. As the shape of the four offset butterfly valve seat is round, a standard inconell O-ring can be used.



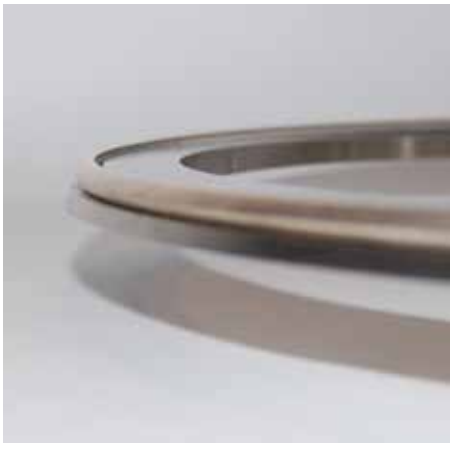
Four offset seal design with Inconell O-ring. Identical wall section in every part results in symmetrical shrinkage

Four offset butterfly valve QUADAX 42". Zero lekage in both directions at full ANSI 600 rating.

New closed disc design supports the shaft perfectly and results in no shaft deflection.

The used inconell O-ring is spring loaded and made of material with the same shrinkage rates as the rest of the valve.
In a triple offset butterfly valve the seal, typically a lamination seal, has to fulfill several functions. As the triple offset butterfly valve is a torque driven valve, the lamination is used as limit stop for the actuator. It must also withstand all pressure-related forces resulting from the delta P in the valve. If the shaft is deflecting in consequence of high delta P in the valve, the lamination must withstand the forces affecting the disc additionally. So the design of a triple offset butterfly valve lamination must find a right compromise between the flexibility and the rigidity so the lamination can fulfill both functions: keep the valve tight and withstand all forces affecting it.
Especially in big valve sizes and higher pressure rates the laminations will be made with thicker and thicker stainless steel sheets and thinner and thinner graphite sheets in between. The laminations will become very rigid but also very inflexible. Typically in applications where the delta P is higher than 60 bar (870 psi) it is getting more and more difficult to get the triple offset butterfly valve tight with zero leakage. The inconell O-ring in the QUADAX valve is placed in a solid, rigid and thick stainless steel plate which can easily withstand all forces affecting it: limit stop of the actuator, forces resulting from the pressure on the disc and the shaft deflection. In this solid stainless steel plate the inconell O-ring is placed in a groove so the O-ring is covered from all sides when the valve is closed. Without any problems it is possible to supply a butterfly valve with zero leakage in both directions even for a full rated ANSI class 900.

The shaft deflection is one of the biggest problems especially when tightness in the reverse direction is required: when the higher pressure is loaded on the clamp ring and not on the shaft side of the disc.
The four offset butterfly valves have a very special disc design i. e. the disc is extended very close to the valve body where the bearings are extended right to the disc. In this design the shaft is not bent but loaded like a shearing pin. Additionally the disc has a closed design to withstand all the loaded forces without loading forces to the shaft. Where in normal triple offset butterfly valve in a size 24 inch the shaft deflection at 20 bar delta P reverse pressure becomes higher than half an inch the shaft deflection in the four offset butterfly valve was measured as a few microns of an inch.



Four offset Inconell O-ring seal. Solid stainless plate withstand all the loads, the soft O-ring has to seal only.

About the author

Dr Gregor Gaida works for müller co-ax ag. He has a Master's degree in electrical engineering and a Phd in mechanical engineering. Dr Gaida started working for Alfa Laval Group, which is now Crane, in 1990, where he developed the Crane MS Valve, which is still on the market. Then in 1997, he became Technical Director at GEMÜ, where he developed the CleanStar line, the BioStar line, electro pneumatic positioner, etc. From 2001 until 2009, Dr Gaida worked an Engineering Office, where he developed amongst others the Zwick TriCon valve, the AMG pneumatic actuator, ABK ball valve, and the High purity Diaphragm Valve. Since 2008, Dr Gaida is the Vice President of müller co-ax ag, developed the QUADAX and CRYAXX line. He has more than 20 patents worldwide.